Saving energy with

Daylighting Systems

Maxi Brochure 14

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energy efficiency

CENTRE FOR THE ANALYSIS AND DISSEMINATION OF DEMONSTRATED ENERGY TECHNOLOGIES

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Contents

Summary

Daylighting is the efficient use of natural light in order to minimise the need for artificial light in buildings. A well thought out building designed with daylighting in mind can have a number of significant benefits for building owners and occupants. Increasing levels of daylight within rooms can reduce electrical lighting loads by up to 70% in some cases. Building occupants generally prefer a well daylit space, provided that attention is paid to avoiding the problems of glare and overheating. Studies also suggest it is beneficial in terms of health and productivity. However, despite the potential benefits, daylighting design often receives little attention.

In 1997, solar design was estimated to be a feature in between 20,000 and 30,000 private houses and only a few hundred other buildings in Europe. However, very few of these buildings incorporated a fully designed daylighting strategy [1]. Daylighting differs from other environmental services in that it is a fundamental element of architecture, while electric lighting or mechanical heating and cooling systems are add-on services that architects can hand over to the building services engineer. When lighting specialists are employed it is rare for them to be asked, or be able, to advise on daylighting. Even when architects plan the window design it is rarely thought of as a lighting element that can provide visual quality and utility, but more as an element of the façade and a view to the outside world [2].

This Maxi Brochure looks at the latest and most commonly used daylighting techniques. Daylighting components fall broadly into three categories [1]:
1) Conduction components – spaces used to guide or distribute light towards the interior of a building, including light tunnels/ducts or pipes, light shelves, or reflective ceilings;
2) Pass-through components – allow light to pass from one room or section of a building to another. These include windows, rooflights, clerestories, etc.;
3) Control elements – designed specifically to control the way light enters through a pass-through component, and include reflective or selective coatings, shading devices, etc.

Many factors affect daylight penetration into an interior space. These include the depth of the room, the size and location of windows and rooflights, the glazing system and external obstructions [3]. These factors usually depend on decisions made at the initial design stage of the building. A well daylit building can often provide sufficient natural illumination for general activities, such as walking around, for the greater part of the day, and adequate working lighting for a substantial part of the year. The potential for daylighting clearly depends on the local climate, e.g. priorities in the warmer, brighter conditions of some countries such as Australia will be different from those in the cooler climates of northern Europe. However much use is made of daylight, it is important to maximise the benefits by ensuring that electric lighting is turned off whenever daylight provides adequate illumination. This involves using lighting controls, and may involve some form of automation.

It is also important to avoid problems such as glare and overheating, which may stem from excessive direct daylighting, and appropriate shading devices should be provided. These may be fixed, such as fins on the outside of a building, or moveable, such as Venetian blinds.

Because the features of any daylighting system are integral to the architecture of a building, the technology is primarily applied to new buildings and incorporated at the design stage. Applying daylighting technology in retrofit applications can prove expensive as it may involve major renovation. However, it is likely to improve the overall energy efficiency of the building as a whole and may prove cost effective in the long term.

This Maxi Brochure aims to increase awareness of the benefits of daylighting by providing an overview of current daylighting strategies. The report deals with buildings in all sectors, as daylighting strategies can often be applied in buildings intended for various purposes.

Of the daylighting strategies discussed here, the current state of development is as follows:

Commercially available: rooflights, clerestories, automatic controls for blinds and traditional shades, highly reflective paint.
In the market: spectrally selective glazing or films, atria.
At the demonstration phase: light pipes and ducts, optical control systems, light shelves and reflectors.

For more information on the related subjects of lighting and advanced windows, please refer to two other CADDET Energy Efficiency Maxi Brochures: No. 1, *Saving Energy with Efficient Lighting in Commercial Buildings*, and No. 12, *Saving Energy with Advanced Windows.*

Energy consumption

Artificial lighting accounts for a substantial portion of the electricity used in buildings. In office buildings for example, it may be responsible for as much as 50% of all electricity consumption [4]. In deep-plan non-residential buildings the lighting load may consume more energy than the HVAC (heating, ventilation and air-conditioning) system. In hospitals only 20-30% of electricity use is generally attributable to lighting; in factories this figure is typically 15%; in schools 10-15%. However, in intensely used buildings (such as hospitals) the total electricity use is very high, so that although only 20-30% is attributable to lighting, the total energy consumption level, and thus energy costs, may still be significant. Clearly there is great scope for realising savings by reducing lighting loads. In many buildings, daylighting may be the ideal way to maximise these savings.

The amount of lighting required in any room of a building depends on the purpose for which it is designed. As a general guide, a corridor may only need a minimal 100 lux, whereas a high-precision task area in a commercial building may require over 1,000 lux. The recommended minimum levels for rooms such as offices and classrooms is 300-500 lux. Clearly, the level of light required will affect whether or not daylight can meet this requirement for long periods throughout the day, and thus determine the need for supplementary lighting.

Most daylighting systems are static architectural elements that consume no energy in use. Others strategies, such as automatic shading devices, may use small amounts of energy, but this is insignificant compared to the savings derived.

Potential for energy savings

To date there has been little significant uptake of building design to maximise the use of solar energy (including daylighting features) in non-domestic buildings. In the European Union (EU) alone, for example, estimated potential benefits could amount to 148 Mtoe annually by the year 2010. Of this, 12% (17.8 Mtoe) may be derived from daylighting [1].

Daylighting does not result in direct energy savings, but savings do occur when the requirement for artificial lighting is reduced through daylighting capabilities. There are few non-residential buildings in which daylight can meet the entire lighting need, but at the same time there are few building types to which daylighting cannot make a significant contribution. The synthesis of a properly daylit space and well-controlled artificial lighting system can produce lighting energy savings in the range of 30-70% in offices [5].

The biggest disadvantage of using daylight lies in its variable and unreliable intensity. This means it cannot "operate" alone. A supplementary artificial lighting system must accompany a daylit space to provide the necessary illumination on cloudy days or if the building is used after dark.

The degree to which daylighting can be used depends greatly on geographic location and conditions. These include latitude, building orientation, seasonal fluctuations in the number of available sunlight hours, the time of day and local meteorological conditions. Buildings located at higher latitudes will require more supplementary lighting in winter and less in summer than buildings located nearer the equator. Other factors influencing the need for supplementary lighting include air quality, whether or not there are any other large buildings or other obstructions in the vicinity, and the reflective quality of these obstructive surfaces. Excessive heating due to solar gain and heat loss due to lack of thermal insulation should also be considered when implementing a daylighting strategy. It is vital to design a strategy that minimises the need for an HVAC system to regulate the temperature of the space. Ensuring an even distribution of daylight in a room provides another challenge to designers and architects. While one side of a room close to the daylight source may have ample lighting, the other side of the room may not. It is important either to design the daylighting system to light a space evenly or, if this is not possible, to compensate for it through artificial means [5].

There are numerous strategies for daylight implementation and these are outlined below. One must carefully consider the above factors and match the particular daylighting requirements to an appropriate strategy.

VERTICAL WINDOWS

Conventional, vertical windows provide the most common and simple means of daylighting, but are less effective in transmitting daylight than rooflights. They are most effective for lighting vertical surfaces that are directly facing and close to the glazed area. For most tasks, a window surface of approximately 20% of the floor area will provide adequate daylighting to a depth of approximately 1.5-2.5 times the room height. Room depths beyond this amount will require supplementary artificial lighting. Daylighting using vertical openings is more dependent on room geometry than using roof openings. Shallow rooms (i.e. in which all areas are close to glazed areas) will benefit most, whereas in deeper rooms the effect furthest away from the window is less, though still significant.

The practice of maximising window areas often prevails as a solution to increase the capacity of daylighting. This practice can counteract the energy-saving capabilities by creating highly different luminance ratios within the space, consequently requiring more artificial light to balance the lighting environment.

Coatings

Excessive glass exposure also dramatically affects other building systems, though measures can be taken to lessen this effect. One such measure involves using window glazing that can reduce heat transfer by approximately 60-80%. Mirrored/reflective glazings, widely used on commercial buildings, have low near infrared (NIR) emittance, but can block visible light transmittance. Low-emissivity (low-e) coatings, coloured glazing, window films and replacing air with a heavier gas between window panes are all effective glazing methods to reduce convection, conduction and radiation through windows.

Shading devices

Shading, using for example automatically activated blinds, provides another alternative to maximise daylighting without affecting other building components. Generally, external shading provides the most effective means of obstructing heat from reaching an interior space. Interior shades protect occupants from immediate glare and direct sunlight, but once infrared radiation penetrates the glazing most is trapped in the room and must be exhausted through ventilation or mechanical cooling. On the other hand, external shades require more frequent cleaning. Often the best solution is to use blinds integrated into the window system [5]. (See the demonstration project *"Automatic blinds in a Japanese office"*, below.)

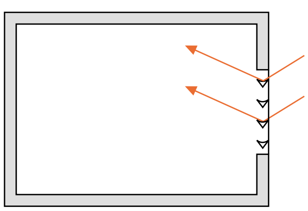

Figure 1: Schematic of daylighting using reflective blinds.

Simply turning the traditional curved louvre slats in a shading blind upside down and giving the upper surface a highly reflective coating can have a marked effect on their ability to transmit daylight (**Figure 1**). Incidental sunlight is redirected into the room, although this can lead to problems with glare. More complex louvre shapes can be introduced that reflect more direct sunlight and only allow light at shallower angles to pass through.

ATRIA AND GLAZED STREETS

Atria are among the more traditional forms of daylighting system. These are interior courts with glazed roofs and are considered part of the building to which they are attached. They allow daylight penetration deep into central building areas and provide pleasant open spaces for users. Glazed streets are similar but longer, as in a street, and can join together a number of buildings. Covered atria have the same daylighting benefits as an open courtyard, but greatly improved thermal qualities. (See the demonstration project *"Daylighting in the SAS Headquarters, Sweden", below.)*

ROOFLIGHTS

Rooflights (also referred to as skylights) are devices that permit light to enter a building via the roof. The use of a horizontal rooflight provides approximately three times the amount of daylight as a vertical window of the same size. Rooflights can be placed closer to the centre of an area and therefore offer more uniform light distribution throughout the space [5]. The downward flow of daylight mixes well with the downward flow of artificial lighting, and when used in combination with a lighting control system this can lead to substantial savings. However, rooflights allowing direct insolation can cause overheating problems and suitable sunscreening must be provided.

Prismatic

Prismatic or angular rooflights have the advantage over flat alternatives in that they can be selective about the light they transmit. They can be designed so that they only allow the passage of lower level light (**Figure 2**). This provides daylighting without overheating, particularly in summer. (See the demonstration project *"Angular selective skylights in an Australian school"*, below.)

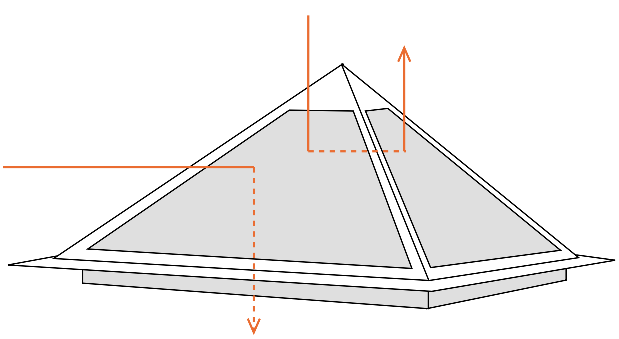

Figure 2: Schematic of a prismatic rooflight.

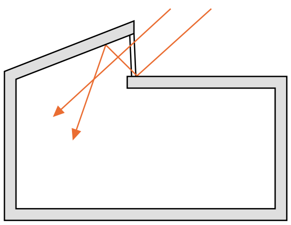

Figure 3: Schematic of a typical clerestory.

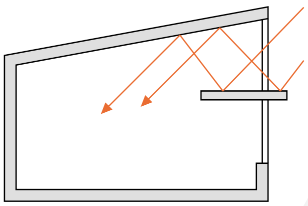

Figure 4: Schematic of a light shelf.

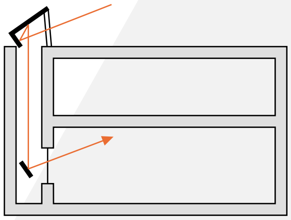

Figure 5: Schematic of a light duct.

Clerestories

Horizontal rooflights often collect more light and heat in summer than in winter, which generally opposes desired conditions. Consequently, vertical or near vertical rooflights, such as clerestories and roof monitors, are more often used (**Figure 3**). These devices are designed according to the zenith angle of the sun, and can regulate the amount of daylight by obstructing the direct rays of the sun during summer, and admitting and reflecting sunlight into the space during winter [5]. As clerestories are generally placed above head height in high-ceiling areas, they provide daylight but no outside view for occupants. (See the demonstration project *"The NREL Thermal Test Facility, United States"*, below.)

LIGHT SHELVES

Light shelves are horizontal reflectors (**Figure 4**) designed to modify daylight distribution by bouncing light deep into a room from the window wall rather than to directly admit daylight. They do this by reducing the direct daylight component and increasing reflection from ceilings, etc. This results in a more uniform distribution of daylight throughout a room. As a result, light shelves are more efficient in rejecting sunlight than displacing diffuse light deep into the interior of a building [6]. Their major benefit is thus derived from increases in thermal comfort, particularly in summer. They should also be designed so that they do not exclude beneficial solar heat gains from insolation in winter.

A successful example of light shelves can be seen in the EU supported "Tax Office Extension" project in Enschede, the Netherlands. More information on this is available from the website (http://erg.ucd.ie/ec2000-hp.html).

LIGHT DUCTS

A light duct (also known as a light pipe or light tunnel) is a rigid device designed to transmit daylight deep into the interior of a building (**Figure 5**). Light ducts offer considerable advantages, although significantly more complex than most daylighting systems. Daylight can be transmitted to virtually any space throughout the building, regardless of the proximity to, or access to, the exterior. Light ducts also transmit light without transmitting heat. They provide interior light by collecting sunlight through heliostats, concentrating the light through mirrors or lenses, and directing it to the interior of the building through shafts. Shafts are traditionally lined with highly reflective polished metal, but newer and more effective alternatives are now being developed which transmit far more light than their metallic counterparts, allowing for longer pipes without optical loss (see below). Light ducts can potentially make a large impact on daylighting design as they offer a cheap and effective solution to reducing lighting loads in internal rooms. (See the demonstration project *"Light tunnels in an Australian school"*, below.)

LIGHTING CONTROL SYSTEMS

No daylighting system will result in energy savings unless it is integrated with a control system to adjust and reduce artificial lighting loads. Control systems can provide constant lighting levels by blending artificial lighting with daylighting to improve building energy efficiency. Ideally, separate sensors should monitor daylight levels at different points throughout a room and should automatically adjust artificial lighting accordingly to maintain a balanced light level across the room. The combined use of daylight and artificial lighting controls can reduce the use of lighting energy by 30-70% in offices. Tests have shown the effect of dimming on fluorescent lamp life and lumen reduction to be negligible, so this is not an obstacle to the wider use of daylighting. (See the demonstration projects "*Local lighting* *controls in Belgian offices", "Daylight control in a petrol station in Norway",* and *"Daylighting retrofit of a state building in the United states",* below.)

REFLECTIVE CEILINGS

Reflective coatings within daylit rooms, principally when applied to ceilings, can substantially enhance daylight penetration into the interior of a room and thus reduce the artificial lighting load. In some cases the reflective surfaces can double the distance into a room that daylighting can meet lighting requirements. Reflective ceilings are best used in combination with other daylighting features, such as light shelves or redirecting blinds, in order to optimise their effect. (See the demonstration project *"Daylighting strategies in the Brundtland Centre, Denmark",* below.)

OTHER BENEFITS OF DAYLIGHTING

Besides energy savings from reduced lighting loads, there are other indirect benefits to be derived from a well thought out daylighting system. Efficient design will also improve living or working environments for residents or employees, by improved optical and thermal comfort.

Several studies have recently been made in the United States concerning the productivity benefits of windows and rooflights. These include a report on a hospital in Pennsylvania where patients who had a pleasant view from their window left hospital 10% sooner than those who did not. A hospital in Canada reported that cardiac patients who were in wards receiving direct sunlight were in hospital for shorter periods, by as much as 11%. A study of student performance in a number of primary schools in California, Washington and Colorado showed that performance was enhanced when students worked in classrooms with high levels of daylight. The improvement ranged from around 7-20% depending on the sites and the subjects. A further study in California looked at the benefits of rooflights on retail sales. This showed that where rooflights were installed, providing between 2-3 times the illuminance of electric light, sales were increased by as much as 40% [2].

Technological advances

Atria and rooflights have traditionally been used to transmit daylight. In recent years the emphasis has been on developing new ways of transmitting maximum levels of indirect daylight into an interior space whilst avoiding the problems of glare and heat gain caused by direct insolation.

Curved light shelves, in the form of anidolic mirrors (fitted internally or externally) can significantly increase the efficiency of daylight transmission. The precise type of curve must be custom designed for each application to achieve maximum benefit. Anidolic light shelves can be fitted either internally or externally (**Figure 6**).

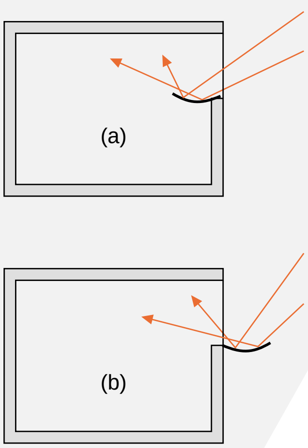

Figure 6: Schematics of interior (a) and exterior (b) anidolic light shelves.

Recent designs of advanced light pipes now incorporate highly reflective polymer coatings or optical fibre cables. These reduce light losses along the length of the pipe and allow a higher percentage of the light entering the pipe to be transmitted to the interior room. This gives the added advantage that the length of the pipe becomes less significant, allowing longer lengths of pipe to be used so that interior rooms, even in larger buildings, can receive the benefits of natural light.

Research is currently underway in the United States into hybrid systems combining the use of solar energy for both power and daylighting.

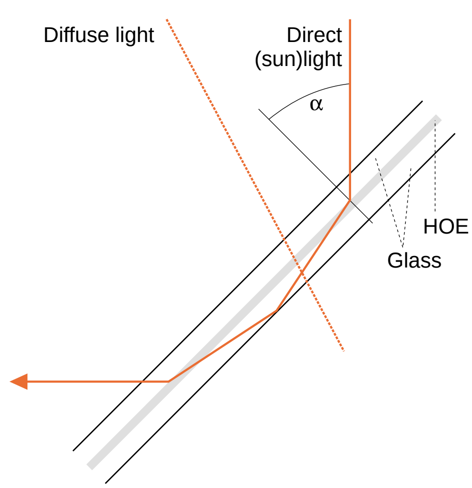

Figure 7: The working principle of holographic optical elements.

The lighting portion of such systems will use filtered sunlight for daylighting purposes, avoiding problems of glare and overheating. A solar tracking device optimises the amount of sunlight available for collection [7].

The use of holographic optical elements (HOE) as a space-free method of redirecting daylight is now being demonstrated in the Netherlands [8]. Laser light is used to etch an array pattern onto a photographic film (in several layers) in order to produce a slight three-dimensional effect. The resulting film is sandwiched between two sheets of glass (**Figure 7**). The HOE reflects light striking the glass at a direct angle, but allows light at more diffused angles to pass through unimpaired. Tests carried out in combination with a reflective ceiling have indicated that the amount of daylight reaching deep into the interior of rooms is double that of situations without the HOE.

Other daylighting initiatives that are still at the development stage include chromogenic and electrochromic glazing [1]. These are also discussed in [9].

IEA SHC Task 21

The objective of Task 21 of the IEA Solar Heating and Cooling (SHC) Implementing Agreement is to develop a scientific, engineering and architectural basis to support the effective and economic integration of daylighting concepts into the design of non-residential buildings. The Task seeks to promote daylight-conscious building design that saves energy through enhanced utilisation of natural light while also enhancing visual comfort and the control of solar gains. The Task focuses on those daylighting systems and strategies that can be applied in new and existing buildings with a high aggregate electricity-saving potential such as offices, schools, commercial, and institutional buildings.

More information on Task 21 and its work can be obtained from the website (http://www.iea-shc.org/task21/).

Demonstration projects

Automatic blinds in a Japanese office [10] [11]

JP

The Tokyo Electric Power Company's R&D centre consists of two buildings connected by a glazed entrance lobby. Office windows are shaded against insolation to prevent overheating. The energy consumption used for lighting, as well as the cooling load caused by lighting, can be reduced by controlling artificial lighting according to daylight levels. In order to balance the needs for shading and daylight, south-facing windows are ventilated and equipped with integral automatically controlled blinds. By adjusting the slat angle of the blinds, direct solar radiation is prevented from penetrating the room beyond a given distance from the window, preventing adverse effects on thermal comfort. If there is no sunlight the slats can be flat or raised. The lighting control system dims or turns off the lights in a specific order away from the window as daylight levels vary. This has reduced the power used for lighting by around 50%.

Automatically controlled exterior blinds in the lobby control lighting levels and thermal comfort in this area. Double glazing with an integral low-e film also improves heat insulation and solar shading, while allowing visible rays to pass through largely unimpeded.

The Tokyo Electric Power Company's R&D centre.

Daylighting in the SAS headquarters, Sweden [6]

SE

The SAS headquarters in Stockholm consists of eight buildings linked together by a single large atrium in the form of a glazed street. In addition to offices the complex also houses shops, restaurants, services and a sports hall. The glazed street is designed to provide a pleasant working environment for employees. Daylight penetration is mainly through the sloped triple-glazed roof. The buildings all have bright white wall finishes to enhance daylight penetration to street level. The daylight factor in the main part of the street is relatively constant at around 16%. Inside the buildings, partitions between corridors and offices are fully glazed, allowing daylight to penetrate into the corridor. Lights in offices are not equipped with daylighting controls, although there is manual control in each room.

The NREL Thermal Test Facility, United States [12]

US

The National Renewable Energy Laboratory (NREL) Thermal Test Facility (TTF) building in Colorado contains high-bay laboratory areas, offices, conference rooms, a kitchen and restrooms. Daylighting is a key factor influencing the design process. The building is rectangular, open plan and faces south. It has a high "aspect ratio" (i.e. the length of the east-west axis is double that of the north-south axis) and a south-to-north step profile with clerestory windows positioned at higher elevations. South-facing glass accounts for 85% of the glazing area. Windows on the north wall in the high-bay space provide additional daylighting benefits.

Clerestories were designed for direct solar gain heating and daylighting. Overhangs allow maximum winter sunlight penetration and reduce summer cooling loads. Clear low-e glass with a high solar heat gain coefficient is used in the clerestory windows. Tinted low-e glass is used in office windows to minimise glare. Only a minimal-use area is not daylit. The high-efficiency lighting is controlled via daylight sensors.

Overall lighting cost savings are around 75% compared to a reference case. The building was designed and constructed at a cost of USD 1,213/m², competitive with average construction costs for commercial buildings in the area. Energy cost savings are roughly USD 3,500/yr compared to the reference case. Reduced lighting accounts for USD 3,100 of this.

Light tunnels in an Australian school [13]

The Park Ridge primary school in Victoria, Australia, was constructed following a design that pays particular attention to natural daylighting of all spaces. Daylight is admitted to rooms via east-west aligned rooflights that direct the light onto acrylic baffles, from where it is reflected onto white-painted ceilings and then onto the work plane.

Angular selective skylights.

The system gives regular even light and saves up to 70% of the school's lighting costs. Skylights (800 mm wide) run the full length of the apex of classroom buildings. Daylight is reflected onto white-painted ceilings via inverted V-shaped acrylic baffles. The skylights are shaded from direct sunlight for 10 months of the year to prevent overheating, but allow passive solar gain in winter. Electric lighting connected to a control system allows individual operation for each space and provides additional lighting only when needed. The energy-efficient features were incorporated into the budget at no extra cost, therefore creating a zero payback period.

Angular selective skylights in an Australian school [14] [15]

The Australian climate provides so much sunlight it is often necessary to shade buildings with wide eaves to prevent glare and overheating. As a consequence rooms are often gloomy. In classrooms where children spend a great deal of time, adequate illumination can be achieved through natural daylighting via skylights. However, conventional skylights often let in too much light and heat when the sun is high. A new type of optical material, the 'laser cut light deflecting panel', incorporated in pyramid form inside the clear cover of a conventional skylight, overcomes this problem. The laser cut panel deflects low-elevation light into the room, but rejects high-elevation light by double deflection.

A number of angular selective skylights have been installed in a school classroom in Queensland in 1995. The skylights eliminate the need for supplementary lighting and provide natural illumination well above the minimum required levels, even in overcast conditions. The installed cost at the first monitored installation (Waterford School) was AUD 800 per skylight. With each classroom requiring four skylights, the cost was AUD 3,200 per room. Energy cost savings from displacing artificial lighting amount to AUD 200 per year.

Daylighting strategies in the Brundtland Centre, Denmark [6] [16] [17]

The Brundtland Centre, located in Toftlund in southern Denmark, incorporates many energy-efficient features including various daylighting systems. The complex consists of a conference room, offices, a science room for exhibitions, lecture rooms and a cafeteria, all surrounding a central glazed atrium. Using daylight for lighting was a crucial parameter in the design process. Two new types of windows were specially designed (daylight and vision windows) and highly reflective ceilings redirect daylight deep into the room (up to 6 metres).

The window facade is divided into three horizontal sections. The upper section uses daylight windows that are not transparent. An integrated triangular (v-shaped) blind system is used to control daylight and solar shading. The centre section contains vision windows. Integrated blinds curve upwards, giving a high potential for reflecting daylight deep into rooms via the reflective ceiling. The lower section has normal fixed windows in one half and windows that can be opened in the other. The reflective ceiling has a highly reflective microstructure made of anodised aluminium and 20% diffusing material that redirects the daylight to the back of the room. Artificial lighting is controlled to maximise energy savings, resulting in energy for lighting being reduced by 70% compared to traditional lighting design in offices. The total investment for this project was DKK 22 million.

Daylight control in a petrol station in Norway [18]

The Statoil Service E-18 petrol station in Lier, Norway was used to find out how much energy could be saved by controlling lighting in roofs over petrol pumps. Originally there were 84 fixtures installed producing approx. 250 lux on the ground. Half the fixtures were replaced

The Statoil Service E-18 petrol station.

with compact fluorescent tubes with electronic dimmers, making it possible to control the light continuously. The luminous intensity was controlled by daylight and the lux value was increased to approximately 400 lux.
A photometric cell was used to continuously register daylight levels and adjust artificial light levels accordingly. The sensor was placed on the top of the roof to ensure that it was not affected by shade from other buildings, trees etc.

As a result of these changes energy consumption was reduced by 65%. Daylight control also doubles the lifespan of the fluorescent tubes, reducing the cost of replacements. The payback period for the additional costs is estimated to be 0.8 years.

Local lighting controls in Belgian offices [19]

BE

A Belgian manufacturer has developed a lighting control system to overcome the intrinsic disadvantages of a centralised control system. The system incorporates light sensors based on light-dependent resistors and standard dimming HF ballasts. The system controls the electric power of artificial lighting in accordance with the luminance of the area below it. Each sensor is continuously adjustable, allowing the user to match the light level to his/her own specific needs and workplace. This allows the artificial lighting levels to be continuously adjusted according to the level of daylight available in each area of a room, thus optimising the use of daylight and maximising the energy savings potential.

When placed at ceiling height of 2.7 m, the sensors (pre-set to standard illumination) measure the luminance of a 6 m² area. At normal levels of incident daylight (for this demonstration, normal was considered to be a window glazing surface equivalent to 20% of the floor area without substantial obstructions) energy savings of 30-70% were measured while maintaining a light level of 500 lux over the workplace.

Daylighting retrofit of a state building in the United States [20]

US

The State of Wisconsin saw the potential to reduce energy consumption in their new administration building by using daylighting to offset the need for electric lighting. Approximately 120 lighting fixtures on the seventh floor of the building were replaced with dimmable ballasts. The fixtures were further categorised into 27 zones controlled by separate photo-sensors. Occupancy sensors were also installed in three of the 27 zones.

The automated daylighting system saves between 650 kWh and 900 kWh monthly and savings range from 0-55% at different locations, depending on the amount of daylight available and the time of year. It was later found that if the sensors had been located over reflective surfaces instead of over dark carpeting or furniture, the potential savings may have increased by 30% to 800-1,200 kWh per month.

Conclusions

The most effective use of natural daylight will incorporate a range of daylighting strategies and an automatic lighting control system to match light levels to requirements, thus minimising the electrical load.

The best way to include a daylighting system in a new building is to adopt a holistic approach to building planning. This requires close cooperation between architects and engineers at the early stages of the design process. Incorporating a daylighting system into an existing building is a more costly process, thus a range of simple energy-saving maintenance measures could be considered first. Cleaning interior walls will increase the effectiveness of daylight and artificial light. Cleaning windows and luminaires to remove dirt will improve their performance (by 10% or more for windows and by as much as 25% for luminaires) [4]. Fitting energy-efficient lamps, reflectors and control systems will also improve efficiency.

There are many considerations when planning a daylighting strategy. A balanced approach is necessary, taking costs into account. No daylighting system is free. Even a simple window costs more than a solid wall. The more sophisticated a daylighting strategy, the more expensive it will be. As daylighting affects artificial lighting, heating, cooling, and ventilation loads in a building as well as general building costs, when assessing the cost-effectiveness of any daylighting system, the costs of installing and running a number of design alternatives should be considered [4]. Efficient daylighting incorporated at the design stage may remove the need for some HVAC equipment entirely, leading to substantial material cost savings and regaining the space no longer needed for bulky equipment. One should also remember that an attractive daylighting strategy can enhance the resale value of any property and may also lead to improved employee health due to less Sick Building Syndrome, Seasonal Affected Disorder, etc. The bottom line will be the overall productivity of the building, including the staff costs, which are by far the most expensive item in any organisation. If windows and daylight can enhance productivity the costs of implementing them will be money well spent [2].

Daylighting clearly offers great opportunities for energy efficiency and comfort in (primarily non-residential) buildings. However, there are still several major technical and market barriers hindering the application of daylighting techniques in building design, which have yet to be overcome. These include [1] [21]:

- architects, decision-makers and the general public tend to be ignorant of the possible benefits of daylighting design. There is a lack of knowledge and information regarding new fenestration technologies and lighting control systems and the ability of such systems to enhance daylight utilisation;
- a perceived lack of appropriate and user-friendly daylighting design tools, including models for innovative daylighting systems and controls;
- a perceived lack of convincing evidence that daylighting can substantially improve energy efficiency and visual quality in buildings;
- lack of industrial lobbying – there is a strong industrial lobby in favour of artificial lighting from electricity utilities and international manufacturers, but no pro-daylighting equivalent;
- lack of legislation – there are few regulations or even codes of practice in place to encourage the use of daylighting and to ensure that it is given due consideration at the design stage.
- as daylighting is largely restricted to new buildings, the rate at which buildings are replaced will determine the progress of daylighting systems as an energy-saving strategy.

It is hoped that the information and demonstration examples contained in this Maxi Brochure will help to raise awareness of the benefits of daylighting systems and will go at least some way to addressing these issues and encouraging the more widespread use of daylighting systems in the future.

Glossary

Anidolic

Non-imaging. In daylighting terms this is usually applied to curved reflecting surfaces that are specifically designed to redirect incoming light to optimal effect.

Chromogenic glass

Changes colour and transmission properties in response to heat, light or electrical impulses.

Daylight factor

The amount of horizontal daylight measured at any specific point in an interior given as a percentage of the amount of horizontal daylight measured simultaneously at the same location in open field conditions.

Electrochromic glass

Glass in which a small electric current varies its absorbance.

Heliostats

A device that directs sunlight onto a stationary target. The rotation of the earth is compensated for mechanically.

Lux

Unit of illuminance, equivalent to one lumen per square metre.

References

This Maxi Brochure was compiled from information in the CADDET Energy Efficiency Register (R), and also from information published in Technical Brochures (T), Newsletter articles (N) and other Maxi Brochures (M). Further reference was made, with thanks, to other publications as indicated.

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USEFUL INTERNET SITES

CADDET Energy Efficiency:
http://www.caddet-ee.org

International Association for Energy Efficient Lighting: http://www.iaeel.org

IEA Solar Heating and Cooling Programme Task 21 (Daylight in Buildings):
http://www.iea-shc.org/task21/

The CADDET Energy Efficiency Maxi Brochure Series aims to raise awareness of key energy-saving technologies that not only save energy but make good financial sense. They draw on information compiled by CADDET Energy Efficiency through its world-wide network of National Teams and from other IEA sources.

Maxi Brochures are written for the benefit of energy managers, engineers or anyone with responsibility for energy efficiency. They are split into a number of short sections which lead the reader through the basics of the topic covered. The reasons why there is a need to make energy savings are examined, and the potential for savings is assessed. After a brief description of the main features of the technologies involved, recent technological advances within the relevant fields are discussed. A number of demonstration projects illustrate how such technologies have already been successfully applied in practice around the world.

When reading this Maxi Brochure, a basic technical knowledge on the part of the reader has been assumed. However, no specific background expertise is required.

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